Household Water Use and Health Survey for the Water Safety Plan

Linden, Guyana

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BACKGROUND

The Water Safety Plan (WSP) aims to identify hazards to drinking water quality that can be introduced at multiple points from “catchment to consumer.” It does not, however, traditionally provide for identifying hazards that could compromise drinking water quality after it reaches the household, such as contamination associated with water collection, storage and treatment practices within the home. This Household Water Use and Health Survey was therefore conducted as part of the Water Safety Plan for Linden, Guyana in order to understand the fate of water from the time it reaches the home to the point of consumption.

The survey, consisting of a household questionnaire and testing of household water samples, looked at issues such as consistency of water delivery, quality of delivered and stored water, community perceptions, and consumer practices concerning water use that impact customer satisfaction and the safety of drinking water within the home. This survey is intended to provide information about customer experience and concerns for the WSP team to consider as they go through the process of system and management evaluation and implementation of changes resulting from the Water Safety Plan.

Five water treatment plants serve the residents of Linden, and each treatment plant serves its own distribution area. Despite some connections between distribution areas, the system is operated (through valve adjustments) such that each area is effectively an independent distribution system. This survey, therefore, is an evaluation of five separate water treatment plant service areas, under the management of Guyana Water Incorporated (GWI), the national water utility of Guyana.

CDC provided technical assistance for survey planning and implementation in collaboration with Guyana Water Incorporated and the Linden Health Department.

OBJECTIVES

Specific aims of the household survey were:

1. to determine the quality of household water at the point of collection and at the point of consumption to determine the quality of water reaching consumers and if deterioration of water quality occurs due to storage and handling practices;
2. to describe water use and treatment practices at the household level, user satisfaction, and perceptions of water quality by consumers;
3. to estimate the prevalence of diarrheal illness in the population, evaluate its possible association with water-related variables, and describe health-seeking behaviors;
4. to determine the quality and consistency of water service provision, identify issues of special concern, and evaluate the impact that interruptions in service or pressure or other service-related issues may have on the safety of water consumed.

METHODS

Sample selection

The survey was conducted in communities served by the five water treatment facilities operated by Guyana Water Incorporated (GWI) in Linden, Guyana: Amelia's Ward, Linden Power Company (LPC), McKenzie, West Watooka, and Wisroc. Additional households from newly developed areas and informal (squatter) settlements that were not connected to GWI's distribution network were also sought for inclusion to allow for comparisons between households on and off of the piped water delivery system. (Table 1, Figure 1)

Because the survey was descriptive and not based on a single outcome variable, the total sample size was determined based upon achieving a 95% confidence interval, ± 5% around the most conservative estimate of several outcome measures of potential interest, including self-reported two-week diarrhea recall, the presence of residual free chlorine in tap water, and household treatment of water. It was determined that a sample size of approximately 500 would provide the desired level of confidence. The sample size of households not connected to the GWI piped water system was not large enough to permit statistical analysis with households on the distribution network; such comparisons are only to identify potential trends between these different areas.

Maps indicating the service areas for each community were provided by GWI and the Guyana Bureau of Statistics. Population estimates were based on the 2001 census, current

GWI service connection records, and estimates of community informants in newer settlements or where there was no GWI service.

Selection of houses within the community was based on stratified systematic sampling. The number of households visited in each community was allocated proportional to the size of the community. The total number of households was divided by the sample size to produce a sampling interval. The surveyors were assigned a random number between one and the sampling interval and counted off this number from one corner of the community to determine the house for the first interview. The surveyor then systematically walked through the community selecting every n^{th} household for inclusion in the survey. If no adult was home at a selected household, the surveyor would return later that same day. If no adult was available upon return, or if the house was abandoned or unoccupied, the next closest house was selected.

Ten local interviewers were employed to conduct the survey. A three-day training was provided to review the questionnaire, household selection, interview techniques and water sample collection and testing. The questionnaire and survey methods were pilot tested in the field. A designated field coordinator managed the daily activities of field personnel. Community sensitization, using local television announcements to inform people of the survey, was done in order to increase participation and for the sake of interviewer safety.

Household Visits

At each selected household, a questionnaire was administered and water samples were tested for free chlorine. For a subset of the selected households, water samples were also collected for microbiological testing.

The household questionnaire aimed to gather information about demographics, sources of water, consistency of service throughout the day and year, possession of a household storage tank, storage and treatment practices within the home, handwashing practices, sanitation, incidence of diarrhea and other illnesses, and health-seeking behaviors. Several questions were aimed toward understanding perceptions of community members concerning water quality and safety and other community and health concerns.

Water Testing

Water samples from each household were tested on site for free residual chlorine using the DPD method and portable colorimeters (© 1996, Hach Company, Ames, Iowa, model CN-66). Samples were collected from each household water source present or available at the time of the survey, including household, yard or shared taps, storage tanks, and drinking water storage containers.

Additional samples were collected from a randomly selected subset of households for microbiological analysis. Surveyors were instructed to collect water samples from a random numbered house directly from the household tap, from the household storage tank, and from the household drinking water container, depending upon which sources were available at the time of the survey. Samples were collected in sterile 100-ml plastic bottles and were transported in cool boxes to a central location and processed within 6-8 hours of collection using the Del Agua Portable Water Testing Kit (Oxfam-Del Agua, 2004). This is a field test kit that tests for total coliforms and *E. coli* using the membrane filtration method, where membranes are incubated on selective media and colonies are counted after 24 hours. Bottled water controls (blanks) were also run each day to test the efficacy of the sterilization technique between groups of samples.

On each day of the survey, water treatment plant operators at each of the five plants were asked to report the free residual chlorine, pH, and turbidity values of water leaving the plant.

Data Management

Questionnaires were reviewed and checked for clarity and cultural appropriateness through question-by-question review with interviewers before and after pilot testing. Completed questionnaires were reviewed with interviewers on a daily basis for accuracy and completeness.

All questionnaire and water sampling data were entered into an Epi Info™ database (CDC, version 3.3.2) and spot-checked for errors. Data were cleaned and analyzed using SAS (© 2002, SAS Institute, Cary NC, version 9.1).

RESULTS

Characteristics of households related to water, sanitation and health are found in Table 2.

Demographics

A total of 535 households from Linden were included in the survey. In most cases, the respondents were women (80%), unless only the male head of household was available at the time of interview. All respondents were at least 18 years of age, and 80% were over 30 years of age.

The average family size was 4.4 persons (range: 1, 18), and the total number of children under age five was 249, or 11% of the sample population. Seventy-three percent of homes were owned, 15% were rented, and 16% were occupied rent-free (either squatters or care-takers). The informal and unincorporated settlements included the Amelia's Ward new housing scheme, the Blueberry Hill squatter area, Watooka Hill, Siberian and Old England.

Thirty-nine percent of respondents had completed only a primary school education, and 46% had completed secondary school. Fifteen percent had completed either vocational/technical school (9%) or college/university (6%). Post-secondary education was higher for men than women (25% for males, vs.13% for females).

Water sources and service

Seventy-nine percent of respondents (419) received water from GWI directly to a tap inside their home, and another 14% (74) used water from a tap in their yard or a shared standpipe as their primary source. Twenty-three percent (125) of respondents regularly collected water from a river, creek or spring; 20% (108) regularly purchased bottled water; 13% (70) purchased water from a refilling station (where tap water is sold by a private company after it is reportedly re-treated); and 41% (222) regularly collected rain water in addition to other sources of water.

Residents of the West Watooka and Wisroc water treatment plant (WTP) service areas were most likely to supplement their tap water with river or spring water (49% and 18%, respectively). Members of the Linden Power Company (LPC) and McKenzie WTP service areas were most likely to purchase bottled water (37% and 34%, respectively) or to purchase water from a refilling station (26% and 38%, respectively). Rain water collection was common in all communities (Amelia's Ward: 35%, LPC: 46%, McKenzie: 31%, West Watooka: 40%, and Wisroc: 38%).

Of those households that had a household tap, 86% experienced interruptions in service resulting in less than 24-hour per day service. Four and a half percent of households reported that their service was regularly out for two to three days at a time. Fifty-six percent had experienced periods of several days without water service in the previous year. Most households (87%) reported that they had problems with low water pressure on most days. The average time for not having water was eight hours per day (range: 0, 22) (Table 3).

Amelia's Ward and LPC WTP service areas experienced the greatest interruptions in water service; 97% and 92% of respondents, respectively, reported daily periods without water. Respondents from the LPC area also reported the highest incidence of low pressure and times of the year when there is no service for several days at a time (Table 3).

During interruptions of service or periods of low pressure, people most commonly used water stored in drums or buckets (40%), river or spring water (37%), rain water (33%), water from their household storage tank (29%), or purchased bottled water (16%). Others responded that they got water from a neighbor's house (8%) or did nothing and waited for water service to return (5%).

The 51 households that were not connected to the GWI distribution network most often got water from the river or spring (40%), collected rain water (42%) or used a public standpipe (14%). Of those households with no GWI connection, 15 (29%) were from Amelia's Ward (with 13 of those from a new housing scheme that has not yet been incorporated into GWI's network). Other squatter or as yet unincorporated areas without water connections were: 3rd Phase/Phase 1B Wismar, the Blueberry Hill squatter area, Old England, and the West Watooka squatter area. Additional households within GWI's WTP service areas, but that were not connected to the distribution network were found in Watooka Hill, Spikeland, Victory Valley, Siberian, Micah Square, Nottinghamshire and Block 22.

Water storage

One hundred fifty-eight households (30%) had a water storage tank. Most (59%) were ground-level tanks, and 41% were elevated. Fifty-two percent of the tanks were plumbed such that water flowed from the distribution system through the tank to the household tap. Forty-four percent of the tanks were not connected to the household tap and were either free-standing or connected to the distribution system only; thus water had a longer storage time. Four percent had a valve system that allowed water from the distribution system to flow either directly to the tap or through the tank to the tap.

Seventy-four percent of respondents reported that their tank had been cleaned in the previous year. Sixteen percent said it had been cleaned one to five years ago and 10% said that their tank had not been cleaned for at least five years. Thirty-one percent (49) of storage tank owners reported that they added chlorine to their tank. Only 9% of tank owners had added chlorine in the previous two weeks.

Ninety-eight percent of households kept drinking water in a container for serving in the home. Most (79%) used closed containers, such as bottles or covered pitchers, for storing drinking water, and 43% used open containers (exclusively or in addition to covered containers), such as uncovered buckets or bowls.

Household water treatment

Eighty-seven percent of households used tap water for drinking; 35% reported drinking it directly (without treatment) and 52% said they treated it before drinking. Those who treated their drinking water at home (from tap or other sources) did so by adding chlorine or bleach (70%), boiling (49%), or using a filter, such as coal, sand or cloth (2%). Twenty-two respondents (8%) stated that their water was treated by settling, referring to the time the water remained in a tank, drum, or other container. A free chlorine residual was found in only 18% of drinking water container samples from households that reported treating their drinking water with bleach.

Water costs

Thirty-eight percent (153) of respondents who received GWI water did not pay for their water service. The annual cost for residential water service for those who did pay was 8,000 Guyana dollars (GY $), approximately $43 USD. Twelve percent (47) paid less than GY $7,000 annually, 39% (157) paid GY $7,000 – GY $9,000 (~$38 – $49 USD), and 12% (50) stated that they paid more than GY $9,000 per year. In most of the latter cases, payments for amounts in arrears from previous years were included. More than 5% of respondents reported having bills in arrears.

Most respondents (67%) did not pay for additional (non-GWI) water. The mean monthly amount paid by those who did purchase additional water was GY $2800 (~$15 USD). Nine percent of GWI customers reported spending more than GY $2,800 per month on bottled water or water from a refilling station or truck. Money spent by GWI customers on additional water was highest in the areas served by the McKenzie WTP (28% of residents) and lowest in West Watooka and Wisroc WTP areas (4% of residents). Twenty-one percent of respondents who were not connected to GWI's system spent more than GY $2,800 per month on water from other sources.

Consumer perceptions and satisfaction

Nearly half (43%) of respondents considered water shortages in their community to be a big problem, while 28% considered them to be somewhat of a problem, and 29% stated that they were not a problem.

When asked if they believed the water from the tap was safe to drink (without secondary treatment), 69% of respondents said that it was not; 17% said that it was safe to drink; and 13% said it was safe to drink it sometimes. When asked why they believed it was not safe, most people (93%) cited the appearance of the water - that it was dirty, cloudy, had particles in it, or had a strange color. Other reasons mentioned were that it made them feel ill (6%), contained bugs or bacteria (6%), had a bad smell or taste (5%), was contaminated with chemicals or pesticides (1%), or had too much chlorine (1%).

Sanitation

About 72% of households (384) used a flush toilet that was connected to a septic tank. Twenty-eight percent used a pit latrine. The average number of users of the pit latrines was 5 (range: 1, 24). In the Amelia's Ward, LPC and McKenzie WTP service areas, the proportion of households with a flush toilet was 92%, 91% and 96%, respectively. In the West Watooka and Wisroc service areas, 66% and 58% of households had a flush toilet, respectively, and pit latrines were more concentrated in those areas. Households that were not connected to a GWI water distribution system had the lowest proportion of flush toilets and most of those (67%) had pit latrines. There is no sewer system in Linden.

Most households (61%) burned their solid waste. Thirty-four percent had it collected by a private or public rubbish collection service; 14% buried it; 12% dumped it indiscriminately on the road, a lot, or in the creek; and 6% carried their rubbish to a dumpsite.

Fifty-six percent of respondents said they used soap always or almost always when they washed their hands and 43% said they sometimes used soap. There was no correlation in this survey between reported frequency of handwashing and diarrhea incidence.

Diarrhea and Other Illnesses

Diarrhea was defined as having 3 or more loose or watery stools in a 24-hour period. A total of 87 cases of diarrhea was reported for the two weeks prior to the survey (representing 4% of the estimated total population, based on an average survey household size of 4.4), including 33 (representing approximately 13%) of children under age five and 54 (representing approximately 3%) of older children and adults.

In most cases (75%), children under age five were taken to a health facility when they had diarrhea. Five (16%) were given a home remedy, and two (6%) waited for it to go away on its own without intervention. Older children and adults were less likely to seek medical care for diarrhea; 20 (37%) went to a health facility, 14 (26%) used a home remedy, 13 (24%) purchased medicine at a pharmacy without first visiting a health facility, and 6 (11%) waited for it to go away on its own without intervention.

When analyzed using a logistic regression model, reported diarrhea in the 2 weeks prior to the survey was not found to have a significant statistical association with any potential risk factors. The 2-week cumulative incidence of diarrhea among children under 5 appeared to be higher with increasing household size and among members of households with pit latrines. Incidence was higher among people with free chlorine residual ≥0.2 mg/L in household drinking water containers. There were no apparent differences in reported diarrhea incidence among children based on having a household tank, having a tap (connection to GWI distribution system), or free chlorine residual levels at the household tap or tank (Table 4).

When asked about other illnesses among children under age five in the previous two weeks, 28 (12%) were reported to have had the flu or common cold, and six (2.5%) had had a skin infection. The cumulative incidence of other illnesses among older children and adults was low; the most common illnesses reported included the flu or common cold (26 [1%]), skin infections (26 [1%]), chronic diseases (9, [0.4%]), and vomiting/stomach ailments (7 [0.3%]).

Community Concerns

When respondents were asked to rate a range of issues in their community, those most often identified as being a “big problem” were mosquitoes (80.5%), HIV/AIDS (79%), rubbish (64%) and water quality (61%). Other problems identified were crime (39.1%), chronic diseases (other than HIV) (47%), respiratory infections (25%), diarrhea (24%), and skin infections (21%). Combining responses for “big problem” and “somewhat of a problem,” mosquitoes, HIV/AIDS, water quality, and rubbish were the most frequently-mentioned concerns (Table 2).

Free chlorine residual testing of tap and stored water

Free chlorine residual from tap water (direct from the distribution system with no storage time in tank) was tested from 313 households (58%). Two hundred and thirty-six (75%) were negative for chlorine, and a total of 293 (94%) had a free chlorine residual concentration below 0.2 mg/L. Nineteen (6%) had a free chlorine residual concentration between 0.2 and 0.5 mg/L, and one (0.3%) had a free chlorine residual concentration greater than 0.5 mg/L (max = 0.7 mg/L). The mean concentration of free chlorine residual-positive tap water samples was 0.29 mg/L (Table 5).

The greatest percentage of tap samples with free chlorine residual levels above 0.2 mg/L was found in Amelia’s Ward (14%) and the lowest percentage of free chlorine residual-compliant samples was found in West Watooka (1%). The mean concentration of free chlorine residual positive samples ($\geq$0.2 and $\leq$3.5) was highest in LPC (0.4 mg/L) and lowest in West Watooka (0.2 mg/L). Table 5 shows the results of onsite free residual chlorine testing from tap, tank and drinking water container samples.

Water from drinking water containers such as pitchers, bottles, or jugs was sampled from 386 households. Three hundred and five (79%) were negative for chlorine, and a total of 355 (92%) had free chlorine residual levels below 0.2 mg/L. Thirty-six (9%) had free chlorine residual levels greater than 1.0 mg/L, including six that surpassed the upper limit of the test method (>3.5 mg/L). The mean concentration of free chlorine residual-positive drinking water container samples (≥0.2 and <3.5) was 1.1 mg/L.

According to respondents, 175 drinking water container samples were untreated tap water. Of these, 145 (83%) had a free chlorine residual level of zero (96% <0.2 mg/L). Of drinking water container samples that had been boiled, 43 (91%) had no free chlorine residual (98% <0.2 mg/L), and 37 (50%) of samples reportedly treated with chlorine or bleach were free chlorine residual-negative (66% <0.2 mg/L).

Water from a storage tank was tested from 135 households. One hundred (74%) were negative for chlorine, and a total of 124 (92%) had a free chlorine residual concentration below 0.2 mg/L. Eight (6%) had a free chlorine residual concentration between 0.2 and 0.5 mg/L. Only three samples (2%) had free chlorine residual concentrations greater than 1.0, and two of those surpassed the upper limit of the test method used (>3.5 mg/L). The mean concentration of free chlorine residual-positive tank samples (≥0.2 and <3.5) was 0.43 mg/L.

When comparing residual free chlorine levels from 43 tap and tank sample pairs available from the same household, five (12%) showed chlorine in the tap sample but not in the tank sample. Seven (16%) chlorine-positive samples showed no difference between tap and tank, and four (9%) had higher chlorine levels in the tank samples than the tap, with three of those from households that reported adding bleach to their tank.

When residual free chlorine levels were compared from 129 tap and drinking water container sample pairs from the same households, where the drinking water was untreated tap water, eight pairs (6.2%) showed lower free chlorine residual in drinking water containers versus tap samples. In 23 free chlorine residual-positive pairs, there was no difference between drinking water container and tap samples, and in 2 cases (1.6%) there was more free chlorine residual in the drinking water container than the tap sample.

Residual free chlorine levels, pH and turbidity of water leaving the treatment plants were provided by the plant operators on each of the seven survey days. The mean of reported residual free chlorine levels of water leaving the Amelia's Ward treatment plant was 0.6 mg/L (range: 0.5-0.7, target: 0.5), the mean pH was 6.3, and turbidity was not taken (this is a ground water source). The mean residual free chlorine from LPC was 0.8 mg/L (range 0.5-1.0, target: 1.0), mean pH was 5.4 and mean turbidity was 3.7 NTU. The mean residual free chlorine from McKenzie was 1.2 mg/L (range: 0.4-2.0, target: 1.0), mean pH was 4.9, and mean turbidity was 8.3 NTU. The mean residual free chlorine from West Watooka was 1.2 mg/L (range: 0.8-1.7, target: 1.5), mean pH was 5.0 and mean turbidity was 9.4 NTU. The mean residual free chlorine from Wisroc was 0.5 mg/L (range: 0.5-0.6, target: 0.5), mean pH was 6.4 and turbidity was 3.1 NTU (Table 5).

Microbiological testing of tap and stored water

One hundred and forty-seven water samples were collected for microbiological testing. Forty-seven were taken directly from household taps. Of those tap samples, 30 (64%) were positive for total coliforms and 11 (23%) were also positive for *E. coli*. Table 6 shows the results of testing for total coliforms and *E. coli* from taps, tanks, and drinking water container samples.

Twenty-two samples were taken from household storage tanks. Nineteen of the tank samples (86%) were positive for total coliforms and eight samples (36%) were also positive for *E. coli*.

Seventy-three samples were taken from household drinking water containers (pitchers, jugs etc. stored in the refrigerator or counter). Of those samples, 66 (90%) were positive for total coliforms and 31 (42%) were also positive for *E. coli*.

When 17 paired samples from taps and drinking water containers of the same households were compared, where drinking water samples were untreated tap water, *E. coli* was found in 10 (59%) of drinking water container samples where the tap sample was *E. coli*-negative. There were insufficient paired samples to compare tank and tap water results.

Of eight drinking water samples that contained water drawn from community springs, all were positive for total coliforms and six (75%) were positive for *E. coli*. Two samples were taken directly from community springs and both were positive for total coliforms (too numerous to count). One of these samples taken directly from springs (One Mile/Wismar) was also positive for *E. coli*, and the other (Old England) was not.

One sample was taken from each of the following sources: water obtained from a refilling station, from a nearby dairy farm, from a bucket of water originally taken from a neighbor's tap, from a creek, and purchased bottled water. All of these samples were positive for total coliforms and the last three were also positive for *E. coli*, including the bottled water sample.

DISCUSSION

The water delivery service provided by GWI to the town of Linden consists of five water treatment plants and three water sources. The West Watooka, McKenzie, and Linden Power Company (LPC) water treatment plants draw water from the Demerara River. The Wisroc treatment plant draws from Dakoura Creek, and the Amelia's Ward treatment plant draws from two wells. In most cases, the distribution service areas for each treatment plant are independent, such that there is a single source of water for each household. The exception is in some areas of Wisroc and West Watooka, where shortages in one system can be supplemented by the other, such that some households may receive water from either source depending upon each plant's capacity to deliver sufficient quantity (depending on demand and source water availability) and quality (depending on turbidity). Thus, the Linden GWI water delivery service can be viewed as five distinct systems. People living in areas not served by GWI generally use water drawn directly from the Demerara River or its tributaries.

Water quality

Most water delivered to the taps of people connected to the Linden GWI distribution system contained no residual free chlorine. The target residual free chlorine levels for water leaving the treatment plants set at each of the treatment plants is quite low. The target of 0.5 mg/L for water leaving the Amelia's Ward and Wisroc plants was determined based on the idea that water from those sources is the cleanest, and therefore would consume the least amount of chlorine in the distribution system. The operators aim for a minimal effective level (to achieve a free chlorine residual of 0.2 mg/L at the most distal point of the distribution system) and to avoid the water having a taste of chlorine, which is considered undesirable by consumers. This minimum level, however, is not being achieved, as evidenced by the lack of free chlorine residual found in tap samples.

Other water quality data reported by plant operators on survey days indicate that there are additional parameters of concern. According to the WHO Guidelines for Drinking Water Quality, median turbidity should be below 0.1 NTU in order to ensure effective disinfection, and that turbidity of 5 NTU has an acceptable appearance to consumers. Turbidity levels above 0.3 NTU are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria (USEPA Primary Drinking Water Standards). Turbidity values in finished water measured on survey days were as high as 15 NTU (see Table 5).

In addition, pH values measured on survey days from waters leaving the three treatment plants sourced by the Demerara River were as low as 4.8 (see Table 5). This may be attributable to naturally occurring bauxite and mining activity. Low pH can cause corrosion of distribution pipes, adversely affecting the taste and appearance of water and can reduce the effectiveness of coagulants used for flocculation.

Total coliforms and *E. coli* were measured from multiple sources (taps, household tanks and household drinking water containers) from a random sub-sample of households. The presence of total coliforms indicates inadequate disinfection and/or the presence of biofilms or leaks in the distribution system. *E. coli* is evidence of recent fecal contamination. The proportion of total coliform-positive and *E. coli*-positive samples found from water taken directly from taps in all five WTP service areas was high (71% and 27%, respectively), indicating that inadequate primary disinfection at the treatment plant and/or breaches in the integrity of the distribution system combined with insufficient free chlorine residual contribute to reducing water quality. Results from GWI's 2007 routine monitoring show that the finished water from all five WTPs was frequently positive for total and/or fecal coliforms, further indicating inadequate disinfection at the treatment plant (see Water Quality Data Analysis Report in WSP).

Inconsistent service also leads to greater reliance on alternate water sources that are generally unsafe for drinking. While nearly all respondents had access to an in-house, yard or shared tap, most stated that they used alternative water sources, such as the river, spring, rainwater catchment, refilling station or bottled water to supplement their tap water supply, indicating that the tap service alone was not considered a reliable source. The results of the small number of samples from alternative water sources that were tested suggest that further testing is needed to evaluate the safety of these sources, including bottled water.

Water treatment

More than half of respondents reported that they treated their water in the home before drinking it. In most cases where the household reported treating their drinking water, however, the water sampled from the drinking water container did not contain any free chlorine residual, possibly reflecting a discrepancy between reporting and practice, inconsistency in treatment practices, or a lack of understanding of what constitutes treatment. In six of the samples of water that had been treated with bleach, residual free chlorine levels surpassed the upper limit of the test method, indicating a lack of knowledge about appropriate home chlorination or possible accidental introduction of bleach into drinking water containers. No households that reported using a filter had filtered water available for testing at the time of the survey.

The proportion of *E. coli*-positive samples was lower in samples that had been reportedly boiled than in untreated samples (27% vs. 62%). While boiling is generally not recommended in a chlorinated system due to its removal of chlorine, in this case where most tap water samples did not have measureable free chlorine residual, boiling appeared to be an effective method for reducing contamination.

Other than boiling and adding bleach, many respondents stated that they treated their drinking water by allowing it to settle in a container, believing that settling constituted treatment for more than just aesthetic concerns. This reflects a lack of knowledge about effective home treatment methods and a need for community education as long as home treatment will continue to be necessary.

Water storage

Most GWI customers experienced periods of interrupted service and low pressure on most days. Inconsistent service often necessitates secondary storage of water in the household, either in tanks and large drums and/or in smaller drinking water containers. Secondary storage increases the opportunity for the introduction of contaminants and increases hydraulic residence time (and hence chlorine dissipation) prior to consumption.

The proportion of residual free chlorine-compliant samples was lower in stored versus tap samples. Both total coliform and *E. coli* counts were higher in samples taken from tanks and drinking water containers than from those taken directly from the tap, likely reflecting contamination through increased handling or from storage in unclean vessels, combined with the loss of chlorine through dissipation. While numbers were insufficient for statistical significance, there was a trend towards decreasing free chlorine residual and increasing microbiological contamination from taps to tanks to drinking water containers. The paired samples from taps and tanks of the same households showed lower residual free chlorine levels in tanks than taps unless bleach was added to the tank. Paired tap and drinking water container samples also showed a loss of free chlorine residual in drinking water containers as compared to tap samples. Our previous studies have shown a similar trend of decreasing chlorination and increasing contamination with increased storage time, from tap to tank to drinking water container.

Water costs

GWI water service is not metered in Linden; rather there is a standard annual residential rate of GY $8,000 (~USD $40) per year, with higher rates for businesses and subsidies for pensioners. With a national average annual per capita income of ~USD $1,130 (World Bank, 2006), this can represent a substantial economic burden for some residents. Customers are sent bills annually and are expected to pay them at the Linden GWI office, but GWI reports problems with non-payment. About half of households surveyed with GWI connections did not pay for their water service or paid less than the annual cost, though they continued receiving water service. This represents economic loss for GWI and a problem with GWI collections. About five percent of households owed large bills from unpaid bills in previous years which they were unable to pay. Some residents stated that they were resentful about over-paying for water when their service was inconsistent, and many spent additional money to purchase bottled or refilling station water for drinking.

Perceptions of water quality

In some cases, the use of alternative sources may not be due solely to a lack of tap service, but rather reflects a preference for other sources. There is a perception among the general population that the water source for the Wisroc water treatment plant, Dakoura Creek, contains high quality water. This perception probably comes from the visual clarity of the water and its low turbidity. The high number of users of river/creek/spring water observed among residents of the Wisroc and West Watooka service areas (which have some overlap in water distribution) likely reflects this perception.

This perception is shared by the water utility (GWI) plant operators. The target residual free chlorine leaving the Wisroc treatment plant is set at 0.5 mg/L. The reasoning for this is that because the source waters have low turbidity, it is considered clean; chlorine is therefore kept to a minimum so that the water will not taste of chlorine.

The results of the microbiological testing, however, do not support this perception. The proportion of total coliform positive tap samples from Wisroc (64%) was greater than from both West Watooka (54%) and LPC (55%). Similarly, the proportion of *E. coli* positive tap samples from Wisroc (27%) was greater than from West Watooka (8%), LPC (18%) and Amelia's Ward (0). Furthermore, the household survey results do not reflect the perceived concern over excessive chlorination, as only 6 (1%) respondents reported that they believed the water was unsafe due to too much chlorine.

Additional water quality data records from GWI's 2007 biweekly WTP and distribution system water testing (see Linden Water Quality Data Analysis Report in WSP) found that the presence of total coliforms and fecal coliforms in water leaving the Wisroc plant was greater than in samples taken from the distribution system, demonstrating that contamination is present in the finished water at the treatment plant and cannot be attributed solely to the distribution system. Further, the 2007 biweekly sampling results indicate that the percentage of total coliform detections in the finished water at Wisroc WTP equaled that at McKenzie WTP and exceeded those at West Watooka and LPC WTPs. Similarly, the percentage of fecal coliform detections in the finished water at Wisroc WTP exceeded those at all 4 of the other WTPs. These findings bring into question the perception that Wisroc water quality is superior to the other surface-water treatment plants.

Water collected directly from springs is also widely believed to be safe and was reported as a preferred drinking water source by some residents. While the number of samples tested was small, total coliforms and *E. coli* were found in samples collected directly from springs and from spring water stored in drinking water containers.

Diarrhea and other illnesses

While no significant statistical associations were found for childhood diarrhea, some trends did appear. The higher incidence of diarrheal illness with increasing household size and among people with pit latrines is consistent with known trends for these risk factors, as both large household size and pit latrines provide increased opportunities for transmission of fecal-oral pathogens. The prevalence of pit latrines was highest among households that were not connected to the GWI water distribution network (newly developed areas or squatter areas), so pit latrine users were more likely to access water directly from the river or creek, increasing the risk of infection through consumption of contaminated water. The West Watooka and Wisroc WTP service areas had a higher number of pit latrine users than other WTP service areas and the highest reported incidences of diarrhea; West Watooka also had the highest number of households obtaining drinking water from a creek or spring. Additionally, it is possible that these same source waters could be contaminated through leeching from nearby pit latrines, and that handwashing practices were poor due to the lack of piped water, potentially further contributing to the higher incidence of diarrhea observed among residents of those areas.

Unexpectedly, we found that diarrhea incidence was higher among people from households where drinking water container samples contained residual free chlorine levels greater than 0.2 mg/L. Two of those five cases, however, came from households where the chlorine level in the drinking water container was greater than 3.5 mg/L. Because of the very small number of cases, it is possible that the results are skewed by illnesses from causes unrelated to water consumption.

While respiratory illnesses and skin infections were mentioned as concerns by 65% and 59% of respondents, respectively, reported incidence of these illnesses was low (0 and 4%, respectively). Concern over these illnesses arises from dust, emissions and waste produced by bauxite mining, which is the economic base of Linden. Exposure, either through water or air, to dust and smoke caused by bauxite mining was frequently mentioned by respondents as an additional concern.

Other community concerns

When asked about their biggest community concerns, the most common responses were: mosquitoes, HIV/AIDS, water quality, and rubbish. The first two probably reflect extensive media campaigns and public service announcements in response to the increasing rates of malaria and HIV in Guyana – amongst the highest in the Americas.

Solid waste disposal is an obvious problem in Linden. With no officially designated site for rubbish disposal, informal dumping sites can be found along the streets, in and near the river, around the market area, and in the woods and undeveloped areas around Linden. This poses a health risk in terms of vector control and injury, and threatens water quality. The frequent burning of rubbish produces an additional risk factor for respiratory illness. Gutters blocked by rubbish can create breeding grounds for malarial mosquitoes, which are a growing problem in Guyana.

LIMITATIONS

This assessment faced several limitations. The sample size was calculated based on the ability to evaluate certain variables, such as diarrheal illness for the entire population size of Linden. It was not sufficiently large to make such associations for each of the water treatment plant service areas independently. This limited our ability to describe associations between diarrheal illness and potential risk factors given the different conditions of each water system.

The number of samples that could be tested for total coliforms and *E. coli* was limited by the capacity of the available testing equipment. The number of microbial testing results, therefore, is small and does not allow for statistical analysis of association with potential risk factors. Only trends could be reported. In addition, this assessment did not include laboratory analysis for chemical contaminants that may be present in the water supply.

Information on illness for all household members was requested from a single respondent, likely contributing to under-reporting of illness incidence. Using two-week recall for diarrhea and other illnesses is also subject to under-reporting due to recall bias. Incidence rates for diarrheal illness in Linden could not be ascertained from health department and clinic data, so comparisons with the results of this household survey could not be made.

Considerable variations in water quality can occur due to seasonal climatic changes that affect the quality of source waters. Operational variations at the treatment plants can also affect water quality. For example, the Amelia's Ward treatment plant was not functioning for several days of the survey due to a damaged well pump. On those days, households collected untreated well water provided by the treatment plant, or used other alternative sources This survey was conducted on seven consecutive days in December, and therefore may not accurately reflect typical year-round water quality, water home storage and treatment practices, or the overall health situation of respondents.

CONCLUSIONS AND RECOMMENDATIONS

1. The results of this assessment indicate insufficient chlorination at all GWI water service areas in Linden. Target residual free chlorine levels leaving the treatment plants should be increased to ensure a free chlorine residual at the most distal points in the distribution system of at least 0.2 mg/L. The determination of appropriate target values should be based upon the results of routine free chlorine residual testing in the distribution system rather than assumptions about source water purity. A schedule of routine monitoring of free chlorine residual in the distribution system, as well as evaluation of possible breaches and/or biofilm contamination, should be established to both determine and maintain adequate chlorination levels. This may require training of plant operators on setting appropriate levels for disinfectants and also a system for regular communication of water quality monitoring results to plant operators.

   Other operational considerations beyond just chlorination levels should be included in this analysis. For example, determination should be made through the WSP of operational and/or structural improvements needed to achieve turbidity levels that will allow for maximum effectiveness of disinfection. Adjusting pH and alkalinity of incoming water may allow for more effective treatment, which would improve finished water quality and potentially reduce the quantity and cost of chemicals for treatment.

Testing of raw and finished water for other potential contaminants identified in the Water Safety Plan should be considered, including chemicals and other microbiological parameters such as *Giardia* and *Cryptosporidium*.

2. Education both to the public and to plant operators should be provided about the risks associated with drinking water directly or untreated from the Dakoura Creek and community springs. Although these waters may be less turbid and therefore appear "cleaner" to some residents than water from the Demerara River, the final water should be treated to the same level of quality as other source waters and should not be consumed directly.

3. Until adequate and consistent chlorination can be achieved at the treatment plants and until consistent service precludes the need for household storage, home treatment of drinking water can be an effective method of improving the safety of drinking water. However, public education on home treatment methods needs to be disseminated as current knowledge is low. Microbiological testing showed greater contamination in water from household drinking water containers than from water taken directly from the tap. Storage of drinking water in secondary containers leads to lower free chlorine residual levels and creates opportunities for

- appropriate dosing with bleach to ensure effective, but not excessive dosage;
- boiling, accompanied by careful handling and storage techniques to reduce the reintroduction of pathogens after boiling;
- settling alone does not constitute an effective treatment method, thus another method should also be used.

4. Water quality is considered a large problem by Linden residents, so improvements in water quality and delivery would likely be met with positive public response. As GWI progresses with the Water Safety Plan, informing the community of improvements to their water service and educating the public about safe handling, storage and treatment within the home could help improve public relations. Local cable television is a widely used medium for delivering public service announcements in Linden and could be used to inform people about actual or anticipated changes to water quality, or interim measures that should be taken such as household water treatment.

5. Diarrhea incidence was most strongly associated with pit latrine use (although still not statistically significant). Improved sanitation would both help to decrease potential contamination of source waters and isolate pathogens from consumers. Therefore, sanitation should be considered an important component of the Water Safety Plan.

6. Improved payment collection and customer satisfaction will need to be addressed if GWI is to recover costs from consumers, as the current payment system is not effectively recovering funds owed. GWI has a plan to install household water meters starting in 2008. Installing a metered system should improve their ability to track payment for water use and increase satisfaction among paying customers since people will be billed only for the water they use. GWI will need to continue to provide special payment provisions for those customers who cannot pay due to poverty.

Table 1: Communities surveyed and estimated population size

GWI WTP service area	Communities	Estimated population of survey area	# of HHs surveyed
Amelia's Ward	Amelia's Ward Central, Amelia's Ward South, Brazina Housing Scheme, Cinderella City, Self Help Area	4,250	74
Linden Power Company (LPC)	Kara Kara Scheme, Old Kara Kara, Rainbow City, Redwood Crescent, Retrieve, Spikeland	4,235	79
McKenzie	Constabulary Compound, Docama Circle, Fair's Rust, Industrial Area, North McKenzie, Noitgedacht, Nottinghamshire, Richmond Hill Surapana, Watooka	4,320	77
West Watooka	1st, 2nd, 3rd Alleys (Wismar Nuclear), Buck Hill, *most of* Canvas City, Christianburg (sections B and C), Half Mile, Silver City, Silver Town, Watooka Hill, West Watooka, Wismar Housing Scheme, *parts of* One Mile and Victory Valley	8,400	142
Wisroc	Block 22, Blueberry Hill, D'Anjou Park, Ho a Shoo, Micah Square, Wisroc, *some of* Canvas City, *part of* Victory Valley, *most of* One Mile/Extension	8,175	138
None	3rd Phase/ Phase 1B, Amelia's Ward New Housing Scheme, Blueberry Hill squatter area, Old England, West Watooka squatter area, Siberian	135	25
Linden Total		**29,515**	**535**

Table 2: survey population characteristics by water treatment plant service area

WTP service area	# of HHs surveyed	Have an in-house tap and GWI connection	Have a water storage tank	Have a flush toilet	Believe their tap water is safe to drink	# of children <5 w/ diarrhea in previous 2 weeks	Paid ≥GY$2800/ yr on non-GWI water	Three highest community concerns
Amelia's Ward	71	66 (93.0%)	38 (55.1%)	65 (91.6%)	26 (36.6%)	0	7 (9.9%)*	Mosquitoes HIV/AIDS Water quality
Linden Power Company (LPC)	78	67 (85.9%)	24 (31.6%)	71 (91.0%)	6 (7.8%)	2 (7.4%)	8 (10.3%)*	HIV/AIDS Mosquitoes Water quality
McKenzie	71	61 (85.9%)	19 (27.1%)	68 (95.8%)	5 (7.0%)	0	20 (28.2%)*	Mosquitoes Water quality Rubbish
West Watooka	134	120 (89.6%)	24 (18.1%)	88 (65.7%)	17 (12.7%)	14 (24.6%)	5 (3.7%)*	Mosquitoes HIV/AIDS Rubbish
Wisroc	130	105 (80.8%)	34 (26.2%)	76 (58.5%)	31 (23.9%)	12 (16.4%)	5 (3.9%)*	Mosquitoes HIV/AIDS Rubbish
No water treatment plant connection	51	na	19 (38.0%)	16 (32.0%)	na	4 (10.3%)	11 (21.6%)†	Mosquitoes HIV/AIDS Water quality
Linden Total	**535**	**419 (78.6%)**	**158 (30%)**	**384 (71.8%)**	**86 (17.4%)**	**32 (12.9%)**	**56 (10.5%)**	**Mosquitoes HIV/AIDS Water quality**

*includes people with GWI connection only
†includes entire survey population

Table 3: Consistency of water service by water treatment plant service area

WTP service area	Have 24-hr/day water service	Average # of hours/ day without service	Experience periods of low pressure	Experience several days/yr without service	Consider water shortages a big problem
Amelia’s Ward	2 (2.8%)	13.5	62 (87.3%)	40 (58.8%)	40 (57.1%)
Linden Power Company (LPC)	6 (7.7%)	8.0	62 (95.4%)	42 (66.7%)	41 (53.3%)
McKenzie	13 (18.3%)	7.3	63 (90.0%)	26 (37.7%)	26 (36.6%)
West Watooka	21 (15.9%)	5.8	103 (78.6%)	66 (50.4%)	43 (32.8%)
Wisroc	23 (17.8%)	7.3	115 (89.8%)	84 (66.1%)	46 (36.5%)
Linden Total	**65 (13.5%)**	**7.8**	**405 (87.1%)**	**258 (56.3%)**	**223 (42.6%)**

Table 4: Potential risk factors for diarrhea and diarrhea prevalence in previous 2 weeks among children under five years of age

Variable	Frequency with diarrhea (%)	Odds Ratio*	Confidence Limit (p-value)*
Hrs/day without water	(range 0-22)	1.01	0.93-1.09 (0.87)
# in HH			
$\geq$7 persons	17 (20.2)	3.09	1.02-9.35 (0.06)
5-6 persons	9 (11.0)	1.50	0.43-5.30 (0.77)
1-4 persons	6 (7.6)	*ref*	
Have tank			
No	27 (14.5)	1.80	0.45-10.21 (0.40)
Yes	5(8.6)	*ref*	
Tap service			
Yes	28 (13.3)	1.35	0.35-5.13 (0.66)
No	4 (10.3)	*ref*	
Type of toilet:			
Pit latrine	17 (18.3)	2.41	0.90-6.44 (0.08)
Flush (septic tank)	13 (8.5)	*ref*	
Handwashing with soap (respondent)			
Always/almost always	17 (13.1)	†	†
Sometimes	15(13.0)		
Never/almost never	0		
Free Cl_2 residual at tap			
$\geq$0.2 mg/L	2 (12.5)	1.12	0.12-10.215 (0.92)
<0.2 mg/L	22 (13.8)	*ref*	
Free Cl_2 residual in tank			
<0.2 mg/L	3 (60.0)	†	†
$\geq$0.2 mg/L	0 (0.0)		
Free Cl_2 residual in drinking water containers			
<0.2 mg/L	20 (11.8)	0.35	
$\geq$0.2 mg/L	5 (27.8)	*ref*	0.09-1.33 (0.12)

*Logistic regression model adjusted for effect of clustering by WTP service area and household
†Unable to calculate due to zero values
ref = referent group for calculating odds ratio

Table 5: Water quality data in different household samples and at treatment plants

WTP service area	Free Cl_2 at tap <0.2 mg/L	Free Cl_2 at tap ≥0.2 mg/L	Mean of free Cl_2-positive tap samples (mg/L)[§]	Free Cl_2 in tank <0.2 mg/L	Free Cl_2 in tanks ≥0.2 mg/L	Mean free Cl_2-positive samples in tank (mg/L)[§]	Free Cl_2 in DWC <0.2 mg/L	Free Cl_2 in DWC ≥0.2 mg/L	Mean free Cl_2-positive DWC samples (mg/L)[§]	Mean free Cl_2 leaving plant on survey days[†] (mg/L)	Mean pH leaving plant on survey days[†]	Mean turbidity leaving plant on survey days[†] (NTU)
Amelia's Ward	19 (86%)	3 (14%)	0.28	35 (90%)	4 (10%)	0.64	54 (91.5%)	5 (8.5%)	0.69	0.56	6.3	-
Linden Power Company (LPC)	55 (93%)	4* (7%)	0.40[§]	22 (96%)	1 (4%)	0.30	43 (91.5%)	4* (8.5%)	1.60[§]	0.79	5.4	3.7 (range: 0, 7)
McKenzie	47 (92%)	4 (8%)	0.27	17 (94%)	1 (6%)	0.30	55 (98.2%)	1 (1.8%)	0.50	1.21	4.9	8.3 (range: 5, 12)
West Watooka	100 (99%)	1 (1%)	0.20	19 (95%)	1 (5%)	0.30	92 (92.9%)	7** (7.1%)	1.68[§]	1.20	5.0	9.4 (range: 5, 15)
Wisroc	72 (90%)	8 (10%)	0.26	29 (94 %)	2* (6%)	0.30[§]	87 (83.7%)	17** (16.3%)	1.01[§]	0.51	6.4	3.1 (range: 0, 5)
None	na	na	na	3 (75%)	1 (25%)	0.20	19 (90.5%)	2* (9.5%)	0.20[§]	na	na	na
Total Linden	**293 (94%)**	**20 (6%)**	**0.29**	**125 (93%)**	**10 (7%)**	**0.43**	**350 (90.7%)**	**36 (9.3%)**	**1.27**	**0.85**	**5.6**	**6.1**

*includes one sample with >3.5 mg/L free Cl_2 residual
** includes two samples with >3.5 mg/L free Cl_2 residual
[§] Excluding samples that surpassed the upper limit of the test method (>3.5 mg/L)
†Reported daily by plant operators on 7 survey days

Table 6: Microbiological test results (total coliforms and *E. coli*) for direct-from-tap, drinking-water container (DWC) and tank samples

Source of water sample	**HH tap – total coliforms+**	**HH tap – *E. coli*+**	**HH tank – total coliforms+**	**HH tank – *E. coli* +**	**HH DWC – total coliforms+**	**HH DWC – *E. coli* +**
Amelia's Ward	2 (67%)	0	3 (75%)	2 (50%)	8 (80%)	4 (40%)
LPC	6 (55%)	2 (18%)	3 (75%)	1 (25%)	7 (88%)	4 (50%)
McKenzie	8 (89%)	5 (56%)	4 (100%)	2 (50%)	8 (80%)	1 (10%)
West Watooka	7 (54%)	1 (8%)	2 (100%)	2 (100%)	19 (100%)	8 (42%)
Wisroc	7 (64%)	3 (27%)	2 (67%)	0	13 (93%)	10 (71%)
None	na	na	5 (100%)	1 (20%)	11 (92%)	4 (33%)
Total Linden	**30 (64%)**	**11 (23%)**	**19 (86%)**	**8 (36%)**	**66 (90%))**	**31 (42%)**

Figure 1: Linden Household Survey Water Treatment Plan (WTP) Service Area Distribution Map